Effect of Biofuel Impurities On The Hot Corrosion of Yttria-Stabilized Zirconia Thermal Barrier Coatings
Constituents Of CMAS And Its Effect On TBC’s

Sources of Contaminants

- Middle East Sand
- Volcanic Ash

CMAS (CaO-MgO-Al₂O₃-SiO₂) Tᵣ ~1250°C

93%ZrO₂ -7%Y₂O₃ (YSZ)

CoNiCrAlY

Hastalloy-X

Thermal Barrier Coating (TBC)

- Essential coating in any gas turbine
- CMAS is highly detrimental for the TBC
Why do we need biofuels?

- Concerns about fossil fuels reliability.
- Stop global warming and greenhouse gas emissions

Jet A – Petroleum Fuel
HEFA – Hydroprocessed Esters and Fatty Acids
FT-S8 – Fischer-Tropsch
SIP – Synthesized Isoparaffin

A commercial aircraft (left picture) and a military F-18 (right picture) being tested for the use of Biofuels blends.  

In biomass, the alkali metals are mostly present in a different chemical form than for coals (Livingston, 2009), and so are much more readily released during combustion.

- There is also a different balance between the alkali metals, with much more K than Na; as with Cl, higher K levels are found in faster growing biomass (Simms et al., 2007a).

Factors that affect the composition of Biomass

- Composition of the soil.
- Drying Temperature
- Harvest Season

Selected minor and trace elements present in a range of different biomass (Simms et al., 2007b)
**Experimental Methodology**

### Different Sample Types
- Solutions of multiple types of impurities.

### Deposition of Impurities
- Air Plasma Spray (APS) and Electron Beam Physical Vapor Deposition (EB-PVD) samples.
- Impurity Cocktail
- Apply different concentrations of impurities over the TBC’s.

### Cycle Test
- 10x to 100x.
- Fast Cycles: 2 to 5 min.
- High Temp Cycles: 25°C - 1300°C.

### Ablation Rig
- Evaluate microstructure.
- Identify secondary phases.
- Study oxidation products.

### Scanning Electron Microscopy
Incorporation Of Biofuels Impurities In a Single Solution (Impurity Cocktail)

- A single solution containing the individual constituents of biofuel impurities.
- No precipitation or segregation is observed in the solution of impurities.
- Instead of burning thousands of gallons of fuels, we can test a single solution with the necessary composition and concentration.

<table>
<thead>
<tr>
<th>Constituent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol (C₂H₆O)</td>
</tr>
<tr>
<td>Calcium Nitrate (Ca(NO₃)₂)</td>
</tr>
<tr>
<td>Aluminum Nitrate (Al(NO₃)₃)</td>
</tr>
<tr>
<td>Magnesium Nitrate (Mg(NO₃)₂)</td>
</tr>
<tr>
<td>Tetraethyl Orthosilicate (Si(OC₂H₅)₄)</td>
</tr>
</tbody>
</table>

• A test of a single solution instead of burning thousands of gallons of fuel.
• Concentration/composition of “cocktail“ are versatile.

CMAS (CaO-MgO-Al₂O₃-SiO₂)
X-Ray Diffraction (XRD) Of CMAS And (Impurity Cocktail)

Chemical Composition: 27.8CaO - 4MgO - 5Al₂O₃ - 61.6SiO₂


Deposition Of Biofuel Impurities Over The TBC

- Clamp
- Spray Gun & Cocktail
- Sample
- Hot Plate

Details:

- Minimum measurable concentration: 0.001 mg/in²
Simulating The Interaction of Impurities In The Gas Turbine

- Full view of the sample as compared to a furnace.
- It is possible to measure the heat transfer.
YSZ TBC Hot Corrosion Study

Control Sample
- Geometry: Squares of 1 in.
- TBC: 93%ZrO₂ -7%Y₂O₃ (Agglomerated & Sintered)
- Bond Coat: Ni(24-25)Cr(5.0-7.0)Al(0.3-0.5)Y

Furnace Sample
- Same as Control Sample
- Cocktail: CMAS Composition
- Impurities Deposited: 1mg/cm²
- Temp: 1250°C - 1300°C
- After Each Cycle
- Microstructure for Reference.

Ablation Rig Sample
- Same as Control Sample
- Cocktail: CMAS Composition
- Impurities Deposited: 1mg/cm²
- Temp: 1250°C - 1300°C
- After Each Cycle
- 4 Cycles of 2min ea.

SEM

Microstructure for Reference.
Control Sample Ablation Rig Experiment

APS Sample | SEM (Reference) | Ablation Rig 4 Cycles | SEM (Last Cycle) | APS Sample (After 4 Cycles)

APS Sample

SEM (Reference)

Ablation Rig 4 Cycles

SEM (Last Cycle)

APS Sample (After 4 Cycles)
Hot Corrosion Furnace Experiment

APS Sample

Impurities Deposited (1mg/cm²)

SEM (Reference)

Furnace (1 Cycle)

SEM (After Furnace Cycle)

APS Sample (After Furnace Cycle)

Crack

Microporosity
Hot Corrosion Ablation Rig Experiment

- APS Sample
- Impurities Deposited (1mg/cm²)
- Ablation Rig 2 Cycles
- SEM (After 2 Cycles)
- Ablation Rig (+2 Cycles)
- SEM (After 2 Cycles)
- APS Sample (After 4 Cycles)

Delamination

Microstructure Damage
Ca, Mg, Al, Si in Solution Greatly Hasten Failure of TBC Subject to Thermal Cycling

### Control Sample
- **No Changes**

### Furnace Sample
- **Macroscopic Cracks**
- **Microporosity**

### Ablation Rig Sample
- **Delimitation of TBC**
- **Microstructural Damage**
Conclusions

• Due to the growing importance of biofuels worldwide, identification of the contaminants that will be found in biofuels and a specific understanding of the negative effects of these impurities its mandatory to avoid failure of gas turbines.

• Even though the chemical composition of biomass is simpler than that of fossil fuels, composition of biomass is highly variable and therefore different types of biofuel blends will have different detrimental effects on the TBC’s.

• The implementation of the methodology explained before, will allow us to study the effect of different combinations of impurities on the TBC.
THANK YOU FOR YOUR ATTENTION